The Dual Task Paradigm: Cognitive Load Effects on Hazard Fixations

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1 ABSTRACT

Recognizing hazards on and off the road when driving is an essential part of being a safe driver. But when an individual is bearing a heavy cognitive load how does this perception of hazards change? Most commonly drivers are distracted by their passengers whilst in conversations [4]. Current research and study focuses on loading the participants' cognitive load to truly test the dual-task paradigm. In short the dual-task paradigm is a procedure in which a participant is assigned a primary task in parallel with secondary tasks [6]. In this experiment the primary task is identifying these hazards on the road while solving a series of rapid fire math problems. There becomes a 'bottleneck' between balancing primary and secondary tasks which can cause adverse effects such as delayed response time. In this study you will find this tradeoff present in the results in how participants fixate longer or shorter on hazard when dealing with dual-tasks.

CCS Concepts: • **Eye Tracking Methodology**; • **Gazepoint Analysis**;

Additional Key Words and Phrases: eye tracking, dual task paradigm, cognitive load, fixations, saccades, hazard detection

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2 INTRODUCTION

A key aspect of driving safely is being able to recognize and respond to potential hazards, even while engaged in other tasks. In 2018, there were 2,841 deaths and approximately 400,000 injuries caused by distracted driving in the United States alone [2]. Distracted driving is defined as behavior that could possibly divert attention away from the primary task of operating a motor vehicle [2]. This kind of activity puts drivers, passengers, pedestrians, and others in nearby vehicles in danger. The most commonly performed potentially distracting activity while driving is speaking with other passengers in the vehicle [4].

Even if a driver is operating his or her vehicle alone, there is still potential for distraction via conversation due to cell phone use. According to a study conducted by the Pew Research Center in 2021, the vast majority of Americans, 97 percent, own a cellular mobile device [3]. Other recent surveys have determined that 85 percent of cell phone owners use their cellphones at least "occasionally" while driving and 27 percent report using their cellphones on half of their trips [8]. Cognitive distraction contributes to a lack of attention from the visual scene in front of drivers. Estimates indicate that drivers who use cell phones while operating vehicles may look at a scene but fail to actually see up to

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50 percent of the information in their driving environment [1]. These statistics are very concerning when looked at concurrently with research studies that include dual task paradigms.

Findings from one experiment that utilized a dual task paradigm concluded that the mental effort of holding a conversation is what leads to a significant decrease in driving performance [7]. Whether the conversation takes place over the phone or in person is irrelevant, as the distraction comes from mental rather than physical preoccupation [7]. Many studies have concluded that the human brain is unable to sufficiently perform two different cognitive activities at the same time [2]. Instead, the brain actually switches between the two different “thinking tasks” as quickly as it can [2]. This fact emphasizes the danger of operating a motor vehicle while participating in conversation, particularly if the conversation requires especially high cognitive load. In this case, cognitive load refers to the complexity of a conversation based on the used amount of working memory resources [5]. Research in this area has found a correlation between increased cognitive load and decreased activity within occipital regions associated with visual processing capabilities [7].

Eye movements and fixations of participants are intimately related to their attention objects in a scene [1]. Due to this fact, we expect to see differences in eye movement patterns when participants are engaged in activities that require high cognitive load. Fixation duration is considered to be indicative of processing time [7]. This paper intends to investigate the relationship between cognitive load and the accuracy/length of fixations on potential hazards within a driving environment.

3 BACKGROUND

3.1 What is Cognitive Load

Cognitive load is the amount of information that the working memory can hold at one time. This can also be thought of as heavy concentration of an individual when doing a task or thinking of a complex problem. In the context of this experiment is how we can ’load’ and individual and see how it effects their hazard perception.

3.2 Previous experiment with cognitive load

In a previous experiment done by Steven W. Savage and Douglas D. Potter they performed an experiment on individuals that consisted of using cognitive load as a independent variable [7]. By using eye trackers they were able to see how well participants were able to identify hazards when loaded by cognitive activities or questions. Their results showed it was more difficult for participants to locate hazards when occupied cognitively with another task [7]. Savage and Potter’s research served as inspiration for our experiment as we incorporated aspects from their experimental design and findings in many different ways.

In their experiment, Savage and Potter hypothesised that participating in mobile telephone conversation has a detrimental effect on measures of processing potential hazards in a driving situation. We derived our hypothesis for our own experiment based on their research and findings that supported their initial hypothesis. Specifically, we hypothesised that an increased cognitive load due to completing mental math problems would result in more inaccurate fixations when participants are asked to locate hazards in an image. Savage and Potter created a within-subjects design, where hazard perception performance was compared between high and no cognitive load conditions. We found this was a simple yet effective way of determining the impact of cognitive load on the dependent variable. For this reason, we deigned our experiment in the same fashion. In other words, we used a 2x2 factorial design for this experiment. While Savage and Potter increased cognitive load without requiring subjects to produce verbal information during the primary task, our experiment took the dual task paradigm a step further. We built on their idea by requiring subjects to not only process mental stimuli (in our case these were mental math problems) but also having them respond by saying their answers out loud.

4 METHODOLOGY

4.1 Hypothesis

We hypothesize that participants will have shorter and more inaccurate fixations on potential hazards in a driving scene while completing a series of math problems due to the mental distraction caused by increased cognitive load.

4.2 Apparatus

We will be utilizing GazePoint along with GazePoint Analysis to conduct our experiment and collect necessary data.

4.3 Experimental Design

The experiment will test a variety of participants based on the control which will be an environment in which no dual-task paradigm elements will be present. This is a within-subjects experimental design, meaning the same participant will be shown images with a changing independent variable. Here, the independent variable present is the level of cognitive workload. The level of cognitive workload can be either none or high, thus our experiment is is a 2x2 factorial design. This allows us to understand the effects of two levels of our independent variable (cognitive workload) on a single dependent variable (fixations on hazards in the scene).

As the control setting, we will collect data from the eye movements of each participant while he or she is not completing any mathematical problems. Following this, we will track the eye movements of the same participant while creating a high level of cognitive load by asking them to complete a series of math problems while identifying hazards. The images of driving scenes with hazards shown will be consistent to minimize incontinence in this experiment. Cognitive load problems/tasks will also be kept fairly constant based on difficulty among participants.

4.4 About GazePoint

The GazePoint apparatus is a research-grade eye-tracking system and video based eye tracker. It uses infrared technology to track movement on a individual's pupil. With this technology it is possible to both visualize a individual's eye path and fixations/areas of interest.

This kind of eye tracker utilizes corneal reflection in order to measure where the participant is looking on the screen. During the eye tracking process, the direction of the gaze is measured by an infrared light that shines into the pupil and the cornea. An infrared camera uses the light to track the reflection vectors that show the relation between cornea and pupil.

The GazePoint appliance is fixed to the laboratory computer which is where the participants were experimented on. One is able to move the GazePoint so it can be correctly calibrated to the individual regardless of height or whether the participant wears glasses or not.

4.5 Participants

The participants from the study were all aged from 18 to 22 years old. All participants had normal or corrected to normal vision. The participants all also had a active driver license and had been driving for greater than 4 years.

4.6 Stimuli

Attached below are a couple of the nineteen stimuli (images) we have shown our participants. This images include real-life dash-cam shots of the road with sometimes polluted streets with cars or pedestrians. These images fluctuate between high density of road hazards I.E pedestrians and low density of hazards (clear road).

Fig. 1. An image of our stimuli

Fig. 2. An image of our stimuli

4.7 Cognitive load participant question

The text attached below are some example questions that we used on our participants during the second half of the experiment. During the second half or first half of the experiment these questions are asked to the participant for accuracy and completion.

Cognitive Load Mental Math Problems	Question: 40 * 40	Answer: 1600
	Question: 25 + 47	Answer: 72
	Question: 94 - 11	Answer: 83
	Question: 94 - 11	Answer: 83
	Question: 72 / 9	Answer 8
	Question: 70 * 3	Answer: 210

5 PROCEDURE

1. Sit participants down and run them through the pre-experiment procedure
2. Calibrate and position eye tracker to the participant
3. Run experiment:

i. Show 9 images for 3 seconds each with no cognitive load Experiment administrator should be silent at this time.

ii. Show 9 images for 3 seconds each with cognitive load present

iii. Read aloud and engage with participants to administer the series of math problems.

4. Collect data (fixations and saccades on potential hazards)

6 RESULTS

From the data we collected throughout our experiment, the following dependent variables from each participant were analyzed:

- The average percentage of fixations on hazards objects in each image (fixations on hazard objects/total fixations in an image)
- The average percentage of fixations on non hazards objects in each image (fixations on non hazard objects/total fixations in an image)
- The average percent of hazards that were fixated on in each image (number of hazards fixated on/total number of hazards in an image)

Summary of results for each user:

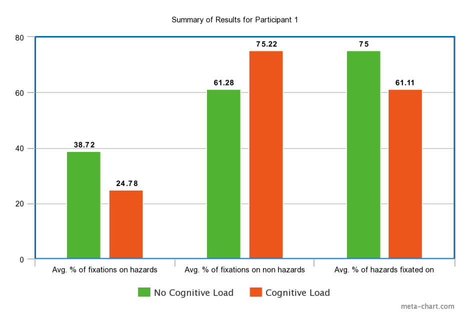

Fig. 3. Summary of Participant 1 Fixations

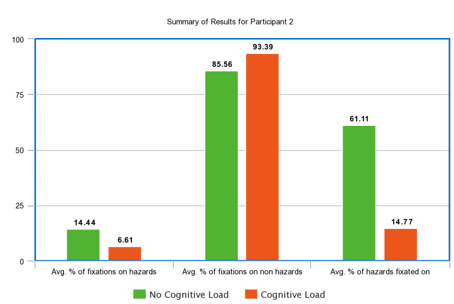

Fig. 4. Summary of Participant 2 Fixations

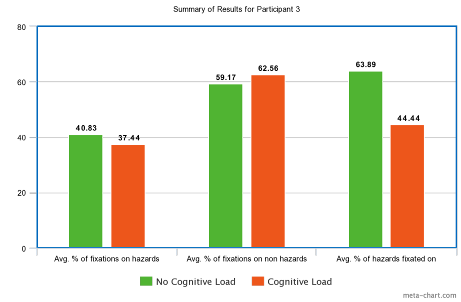

Fig. 5. Summary of Participant 3 Fixations

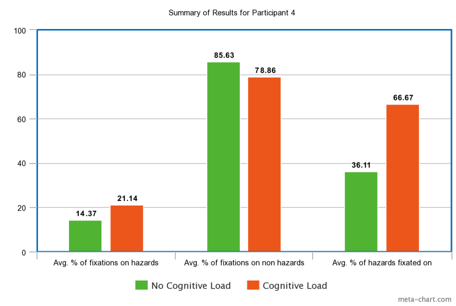

Fig. 6. Summary of Participant 4 Fixations

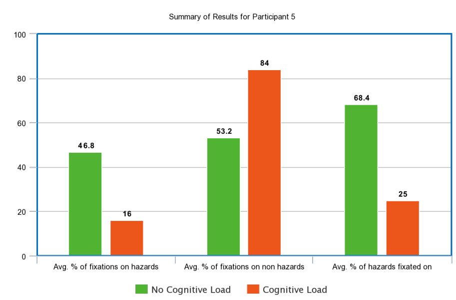

Fig. 7. Summary of Participant 5 Fixations

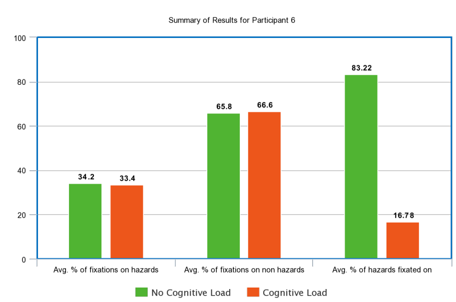

Fig. 8. Summary of Participant 6 Fixations

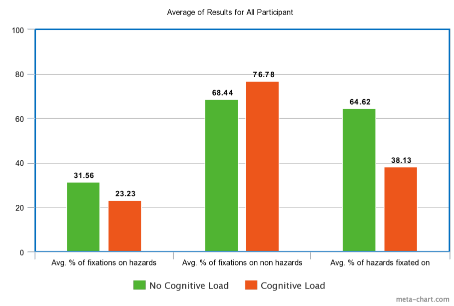

Fig. 9. Summary of Fixations Across All Participants

7 DISCUSSION

In the results we collected, "hazards" are defined as objects in a driving environment that require attention by the driver in order to ensure safety. Examples of hazards in our stimuli include other vehicles in the same lane, pedestrians crossing the street, cars backing out of parking spots, etc.

As seen above in figures three through eight, in five out of the six total participants, the average percentage of fixations on hazards was greater when the participant was not faced with cognitive load. Previous research suggests that fixations are a sign of a participant's attention towards a specific object in a given image or stimuli [2]. While on the road, it is crucial for a driver to correctly identify and respond to any potential hazards in their environment.

From our findings we can conclude that when a participant is given tasks that increase their cognitive load they are less likely to perceptive and/or locate hazards on the road. This supports our hypothesis that of participants will have fewer accurate fixations on hazards in an image of a driving scene. As we see from our results section there was an average of a 8.33 percent increase in hazard fixations across all participants when they did not have cognitive load tasks present. We can also see in figure nine that the average percentage of hazards fixated on out of the total for non-cognitive load was 64 percent, versus only 38 percent of hazards were fixated on with cognitive load. This is significant as it shows that when faced with cognitive load, participants are nearly twice less likely to identify a hazard in a driving environment.

The results turned out in this manner due to how cognitive load effects the brains function to identify objects on and off the road. When a participant was loaded with cognitive tasks we immediately saw the direct impact it had on perception and rate of identification (if at all) of a hazard. These findings could be leveraged in future studies in regards to the dual task paradigm in relation to driving.

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